REFRACTORY METAL/SILICIDE MULTIPHASE SYSTEMS FOR HIGH-TEMPERATURE STRUCTURAL APPLICATIONS

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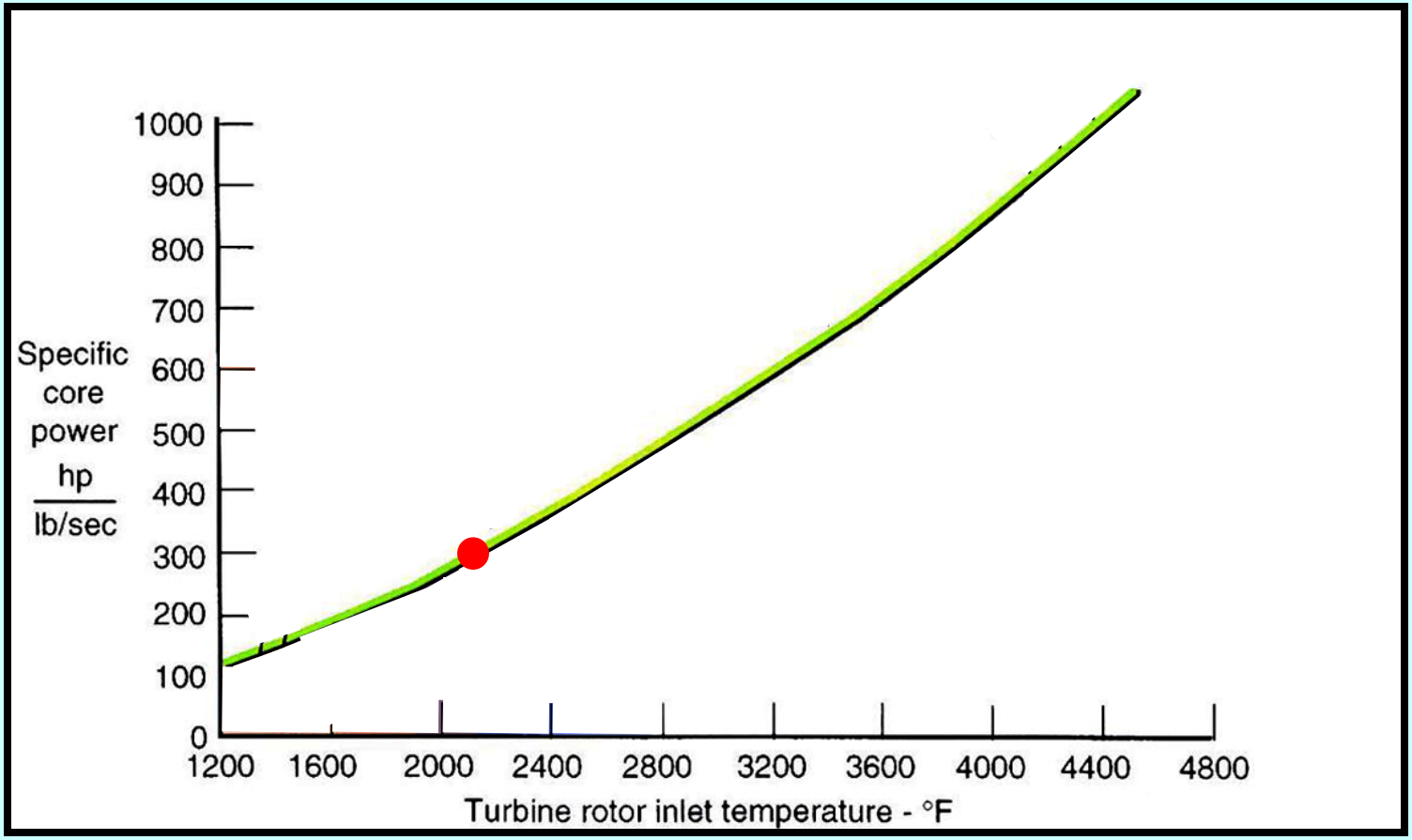
OPERATING TEMPERATURE VS SPECIFIC CORE POWER



High Operating Temperature ⇒ High Thrust

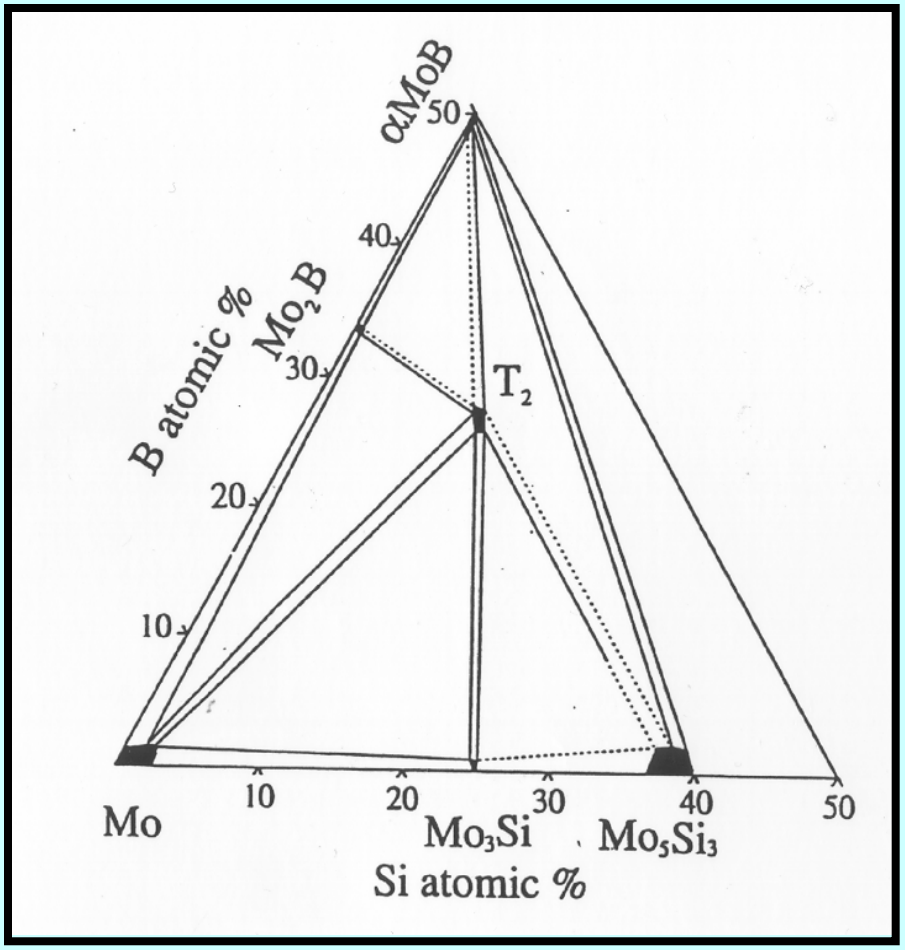
High Specific Strength ⇒ High Structural Efficiency

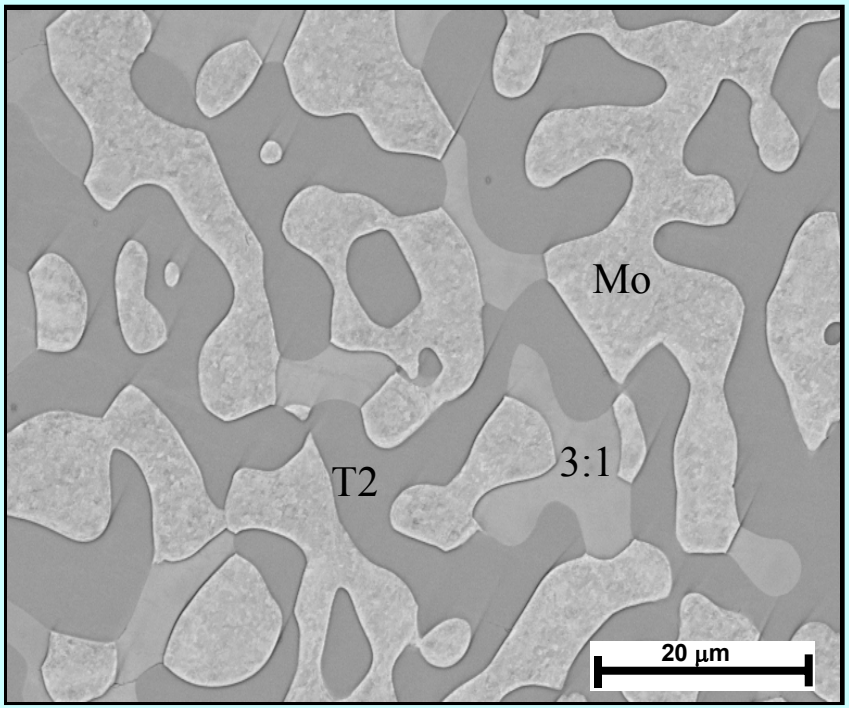
Data from Dr. B. L. Koff, Pratt & Whitney, 1996

ADVANCED AIRCRAFT ENGINES – HOT SECTION MATERIALS

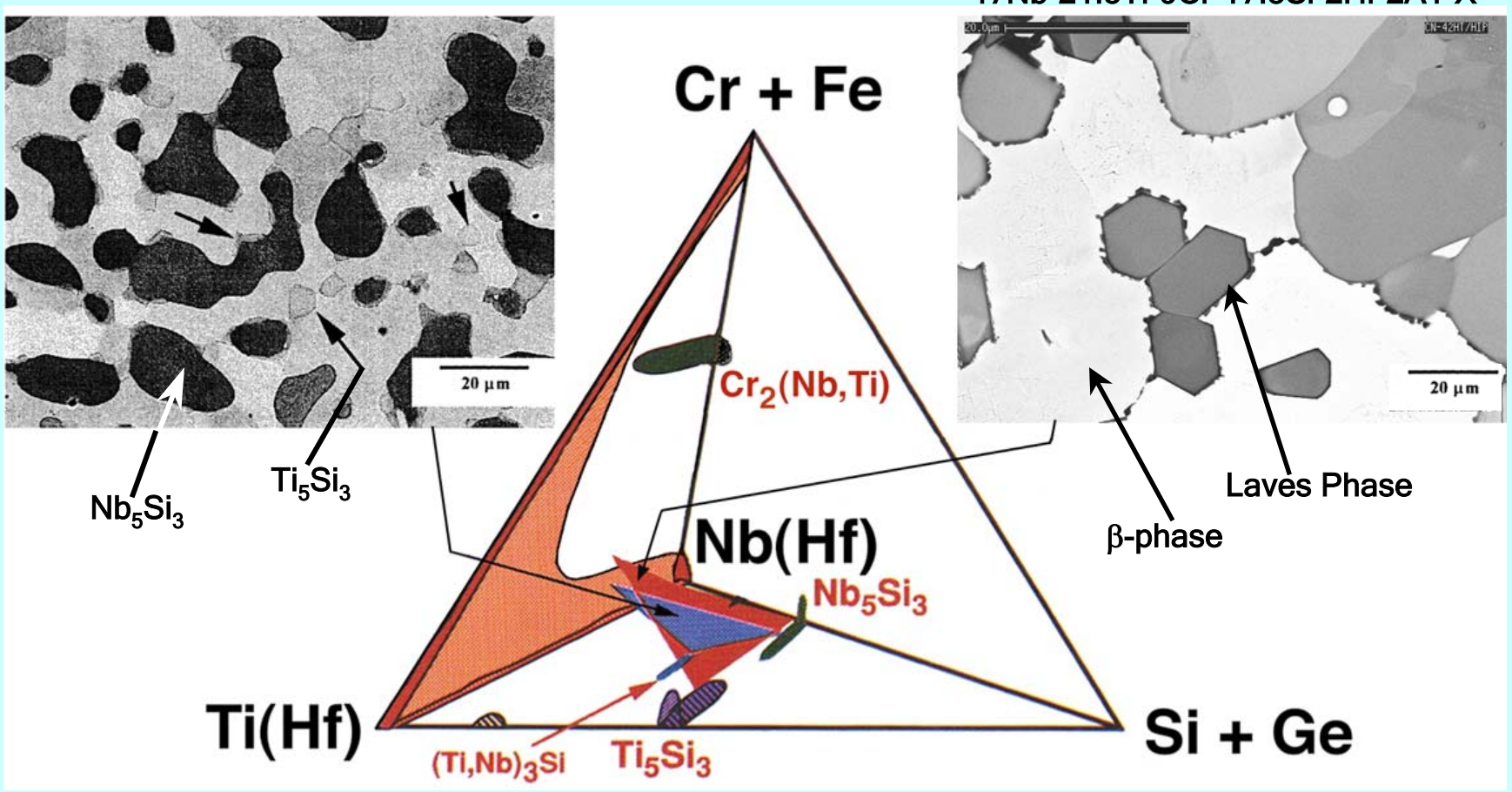
Temperature	600°C to 1350°C
Properties	Oxidation Resistance Toughness Strength / Creep Resistance
Candidates	Mo- Si - B Nb – Ti – Cr – Si – Al - ….

Mo-Si-B PHASE DIAGRAM (1600°C) & MICROSTRUCTURE





PHASE SPACE OF INTEREST @ 1400°C: Nb/Nb Silicide Alloys

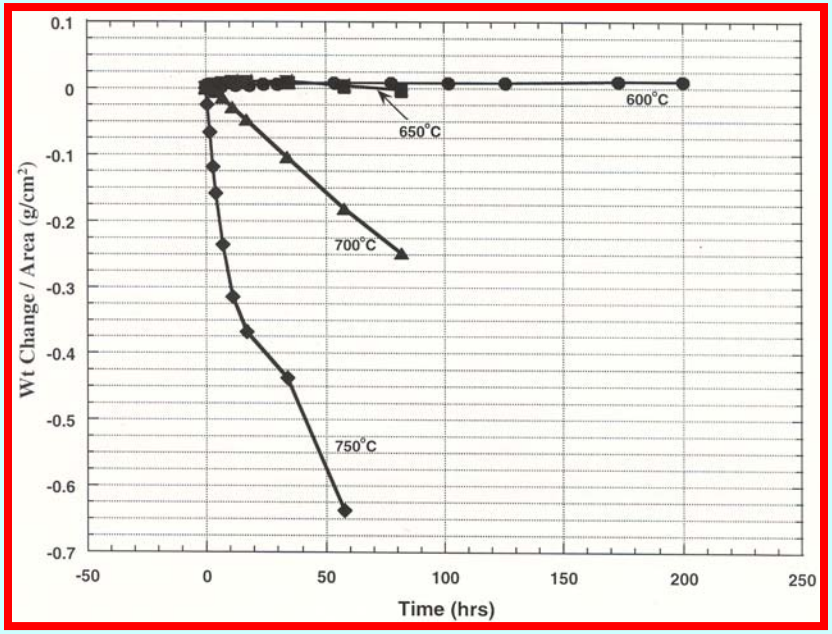


*PHYSICAL PROPERTIES**

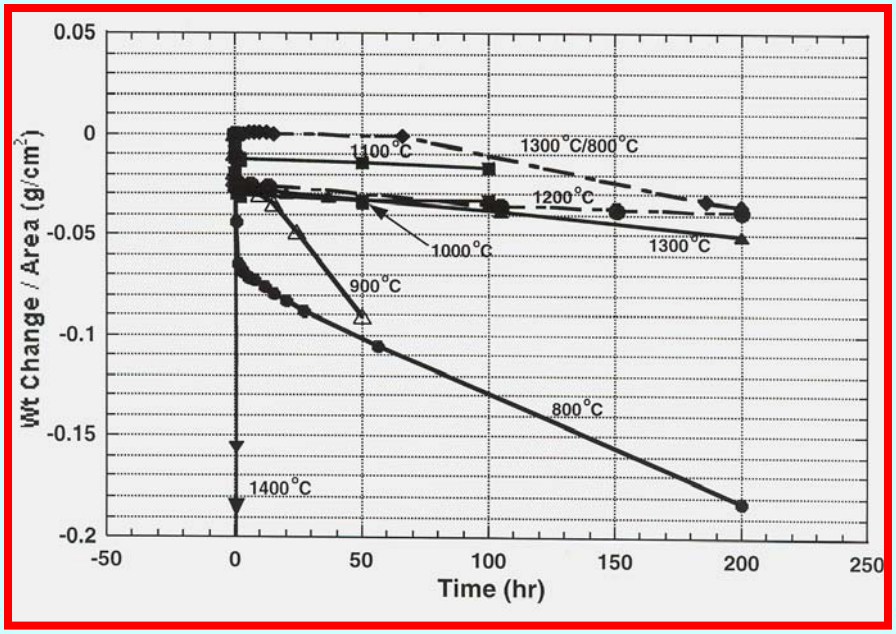
PROPERTY	Mo-Si-B	Nb-Ti-Cr-Hf-A1-Sn
Density	~ 9.5 Mg/m^3	~ 7 Mg/m^3
Melting Temperature	~ 2100°C	~ 1700 - 1800°C
Thermal Expansion	7 - 11x10^{-6} $\mu m/\mu m$	8.1 - 8.6x10^{-6} $\mu m/\mu m$
Elastic Modulus	327 - 171 GPa	158-130 GPa
Thermal Conductivity	49.9 - 112 W/m-K	8.6 - 28 W/m-K
Thermal Fatigue Resistance = $k K_{IC} / E\alpha$	~ 15 x 10^4 (RT)	~ 7 x 10^4 (RT)
Impact Resistance	~ Very Low	Low (Acceptable)

*Sources: Literature, GE CRD, P&W (Private Communications), NASA

CYCLIC OXIDATION KINETICS OF Mo-12Si-12B FROM 600-1400°C

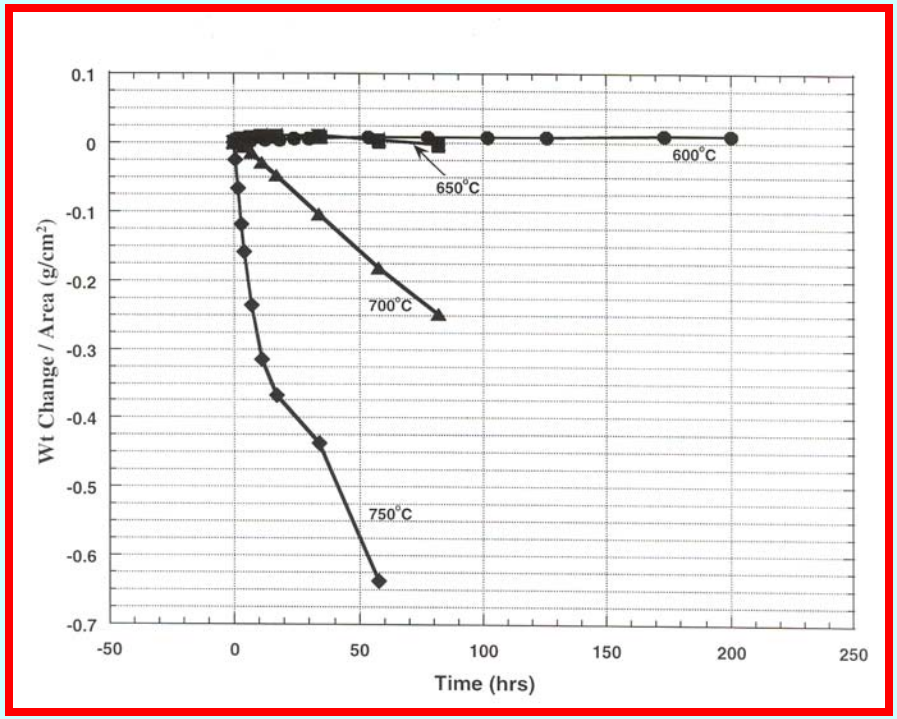


600 - 700°C



800 - 1400°C

CYCLIC OXIDATION KINETICS OF Mo-12Si-12B FROM 600-1400°C



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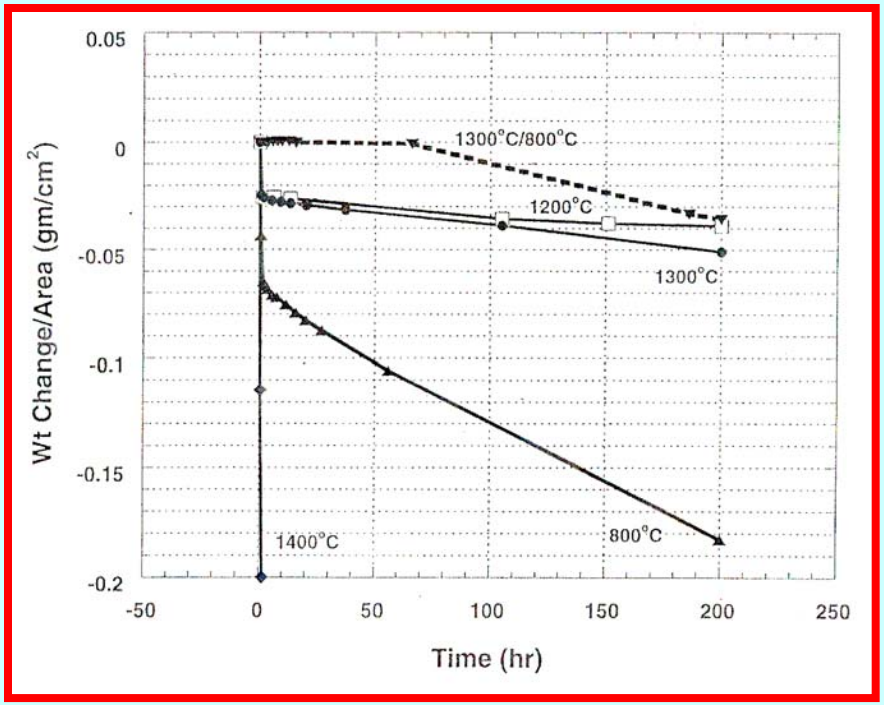
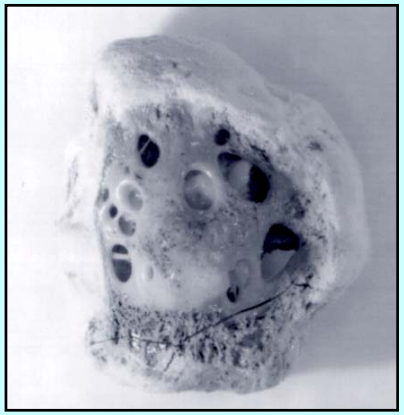


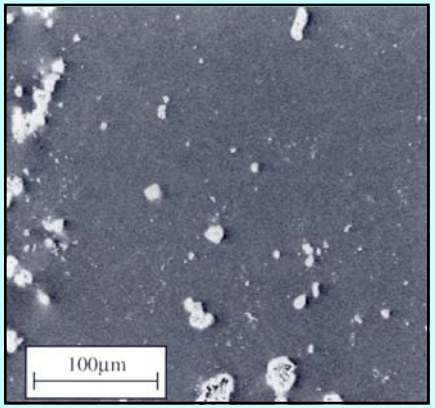
800 - 1400°C

OXIDE SCALE MICROSTRUCTURES: Mo-12Si-12B

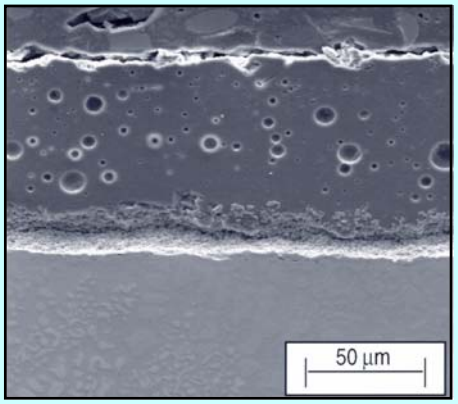
700°C / 82 h



759°C / 58 h



800°C / 200 h



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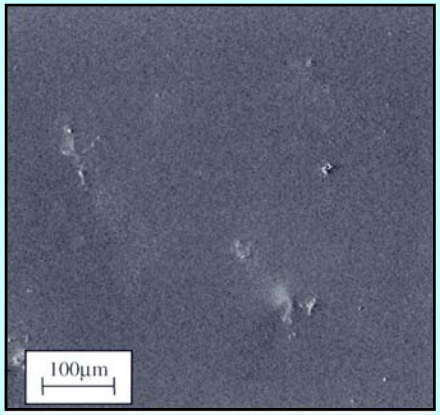
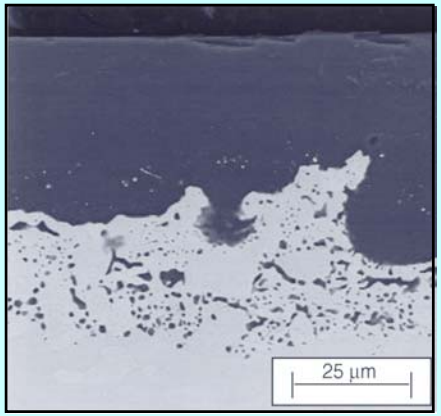
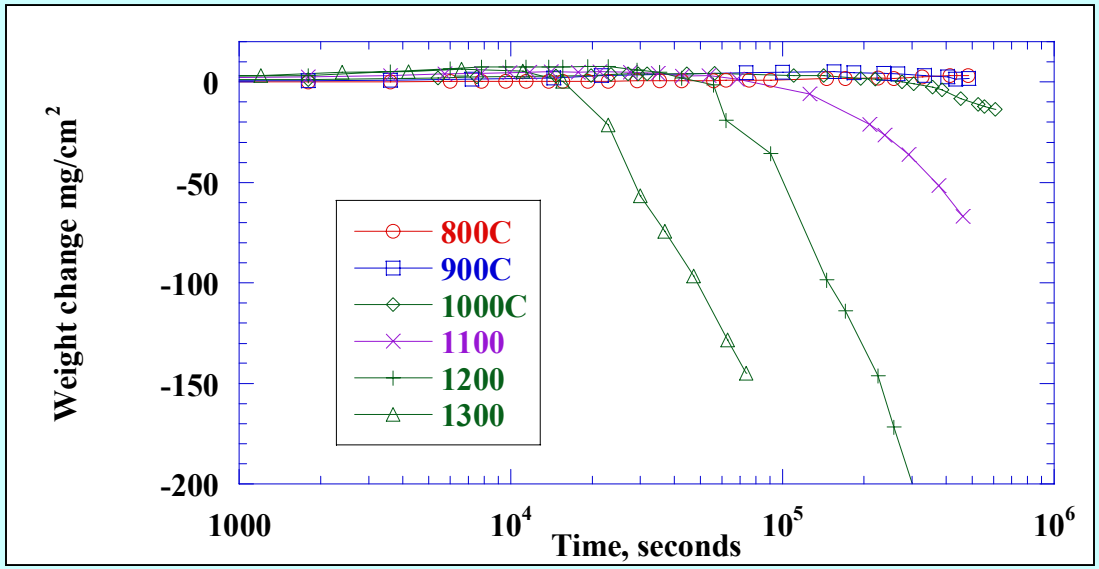


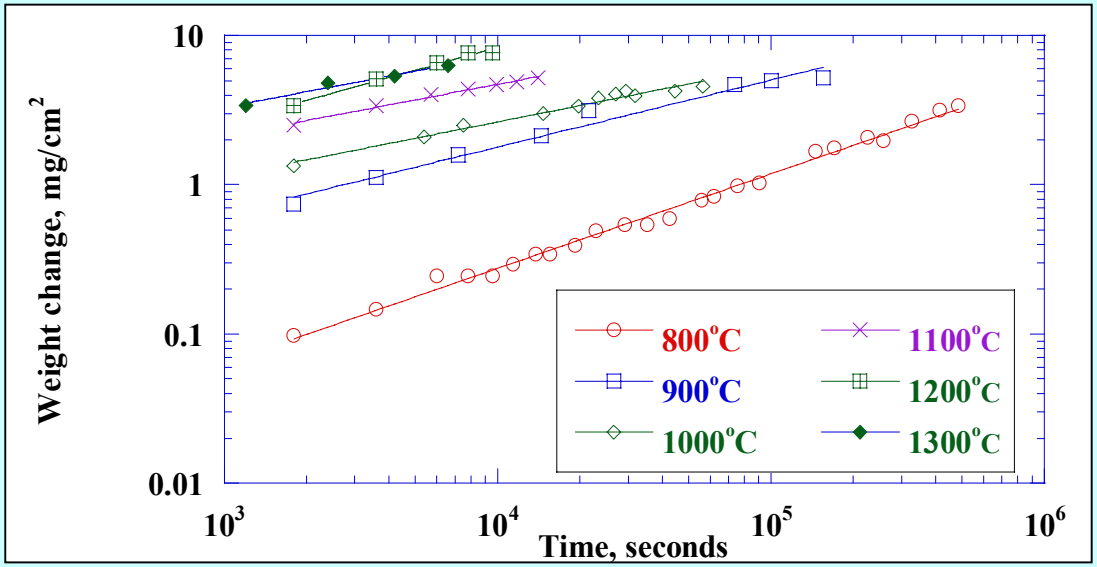
1300°C / 200 h



1300°C / 200 h

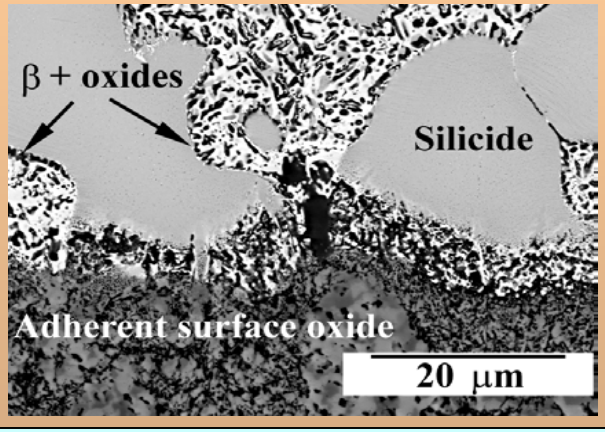
OXIDATION KINETICS OF Nb / Nb SILCIDE ALLOYS

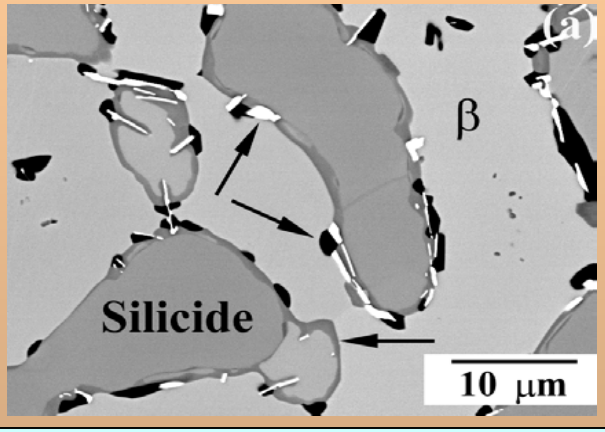




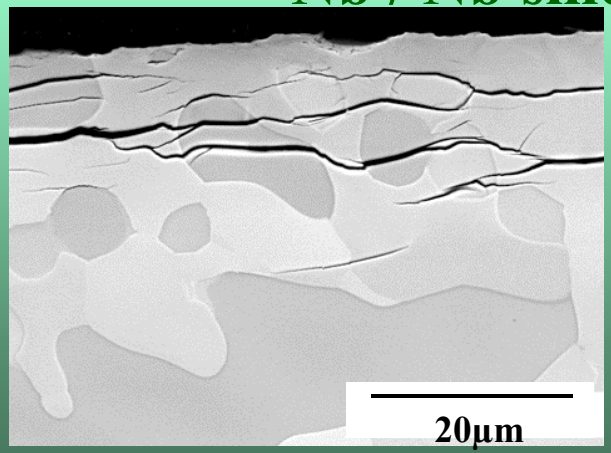
OXIDATION MICROSTRUCTURES

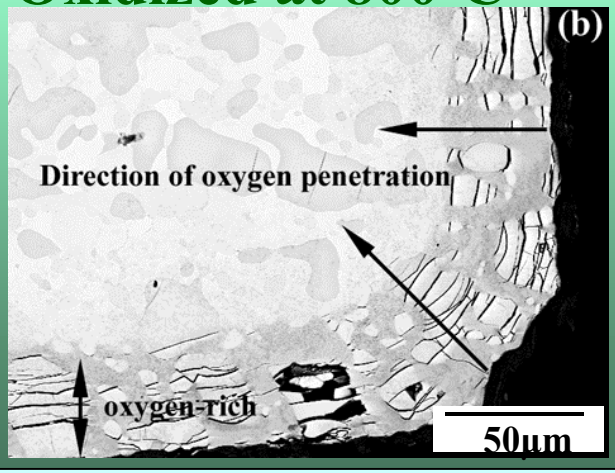
Nb / Nb silicide Oxidized at 1200ºC





Nb / Nb silicide Oxidized at 800ºC





OXIDATION MECHANISM COMPARISON

Mo-Si-B

- Competition Between Formation of β-SiO_2 and Voltalization of Mo (MoO_3 Gas).
  - Below 800°C, Evaporation of Mo Dominates
  - Above 800°C, Protective β-SiO_2 Forms

Nb-Ti-Cr-Si-Al-Hf-Sn

- Formation of Complex (Nb Ti) and Si Oxides.
- Growth Stresses (Spallation) Limits Duration of Oxidation Protection.
- Low Temperature Substrate Silicide Cracking due to Internal Oxidation of Nb_{ss}.

PROCESSING

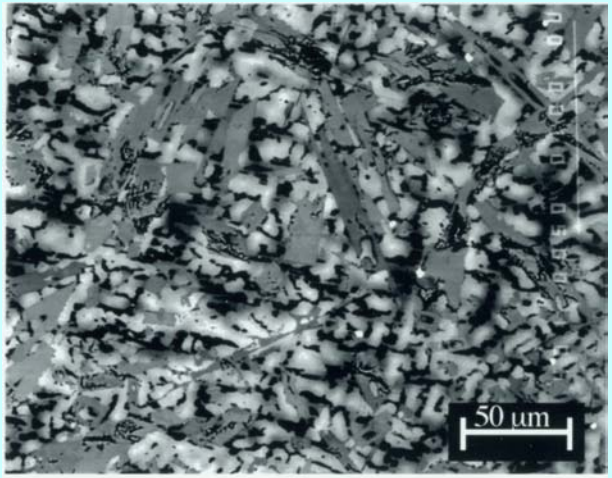
Mo-Si-B

- Small Button Casting + Heat Treatments
- Prealloyed Powder ➡ Sintering + Hipping ➡ Hot-Extrusion

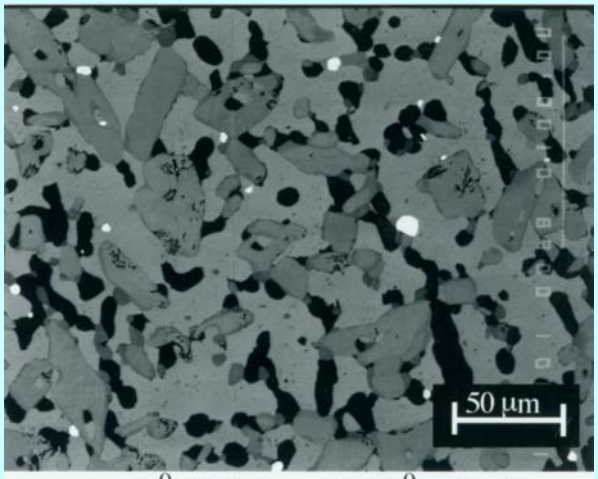
Nb-Ti-Cr-Si-Al-Hf-Sn

- Induction Skull Melting (6.25 cm diam. X 60 cm long ingots) ➡ Hot Extrusion.
- Plasma Rotating Electrode Process (PREP) Powder ➡ Hot Extrusion.
- Gas-Atomization Powder ➡ Hot Extrusion.

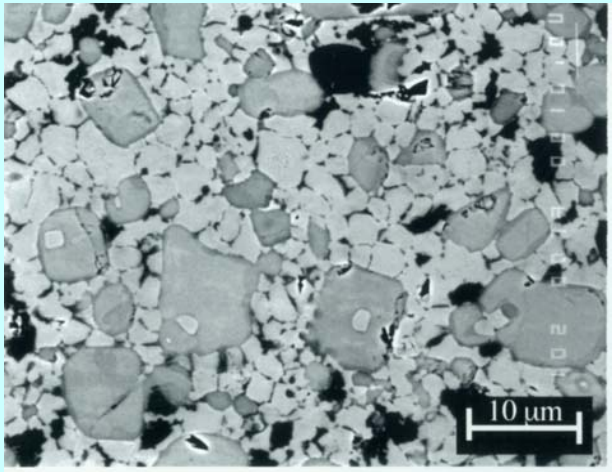
Nb – 21.4Ti – 14.3Cr – 14.4Si – 2.1Hf – 2.4Al – 1.25Sn



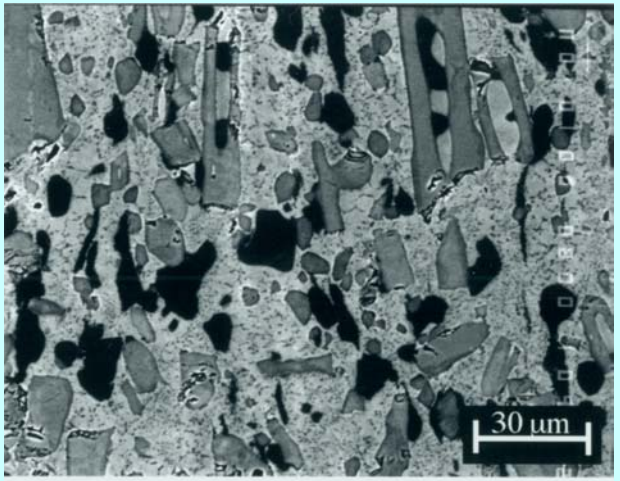
As Cast



1300^0 C/24h + 1400^0 C/76h



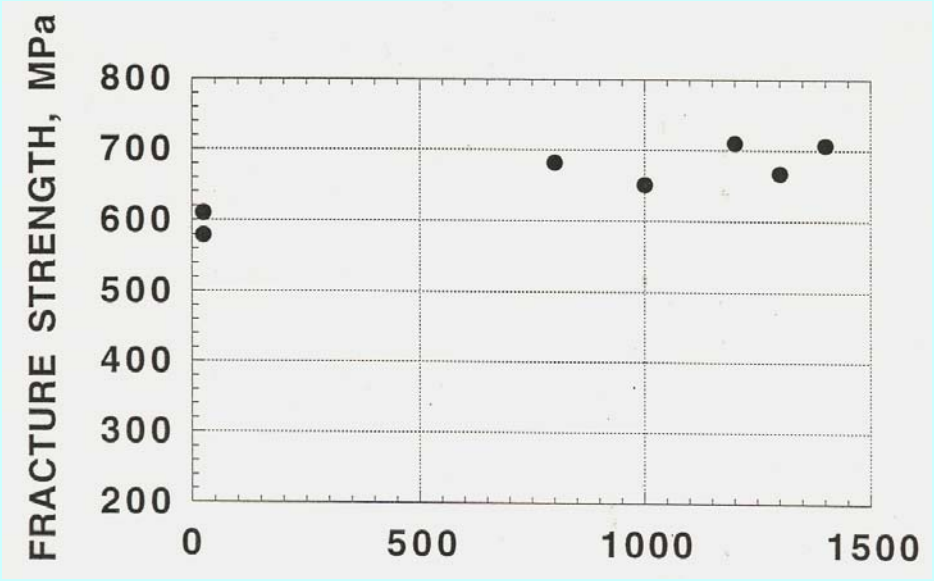
Tran.

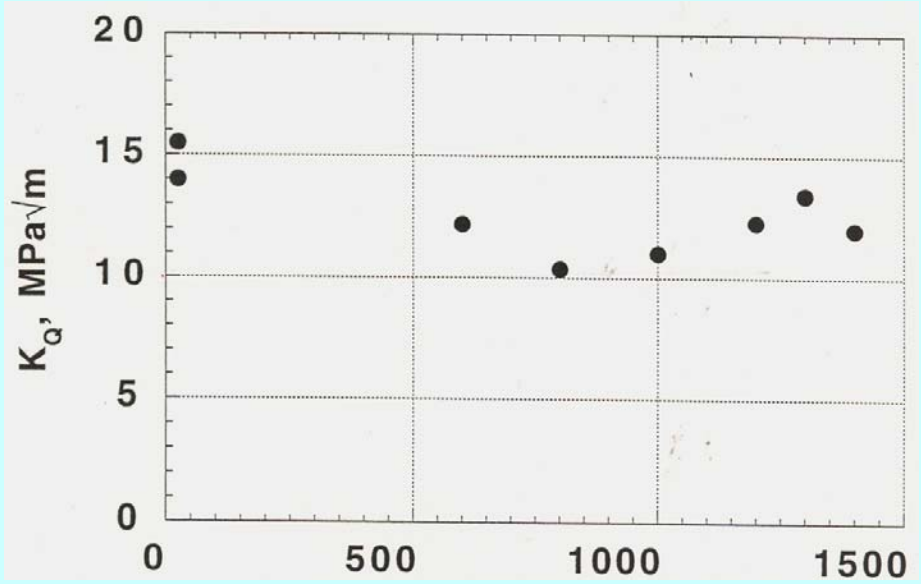


Long.

Homo. + Extruded (1350°C/6:1 R)

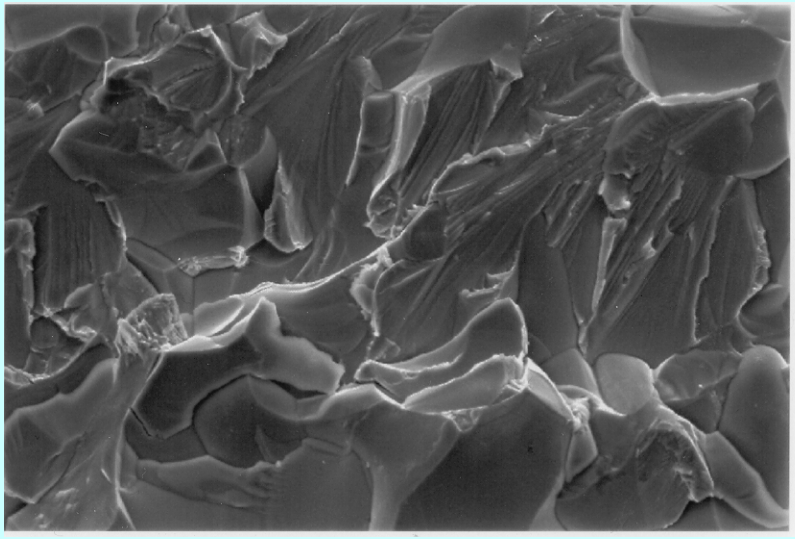
MECHANICAL PROPERTIES: Mo-12Si-12B



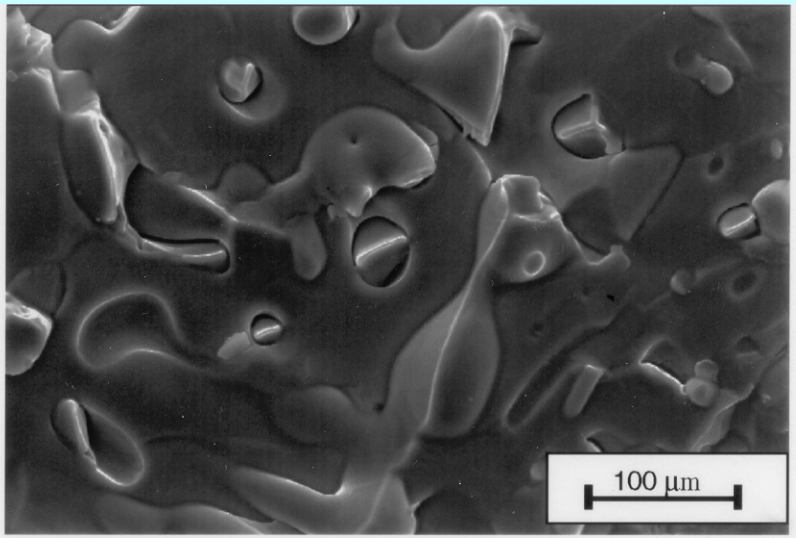


Temperature, °C

FRACTURE SURFACES: Mo – 12Si – 12B

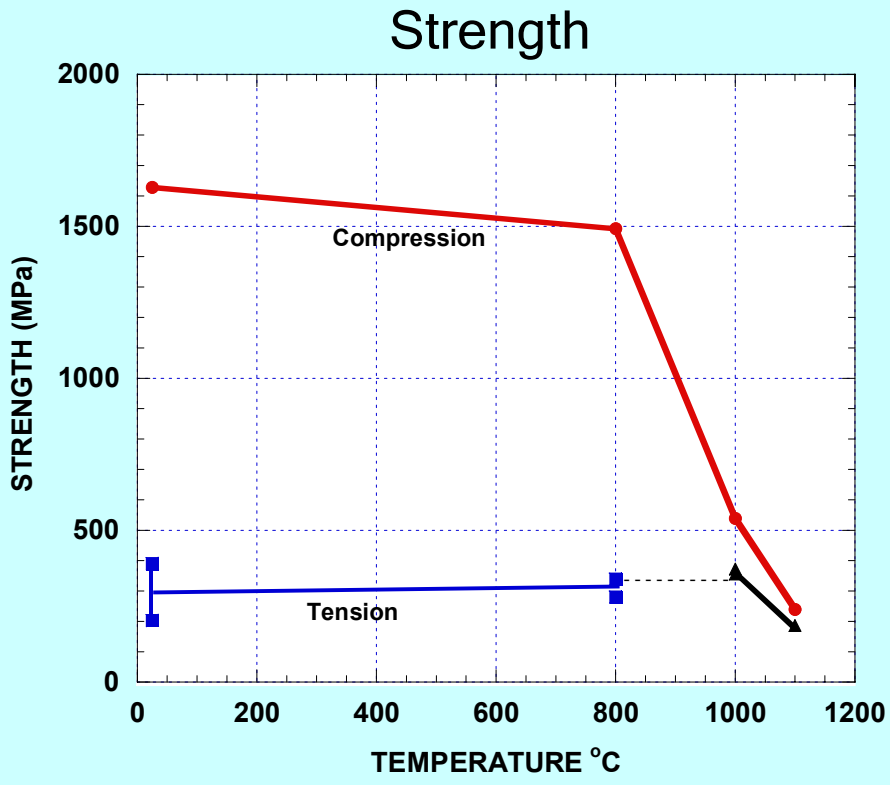


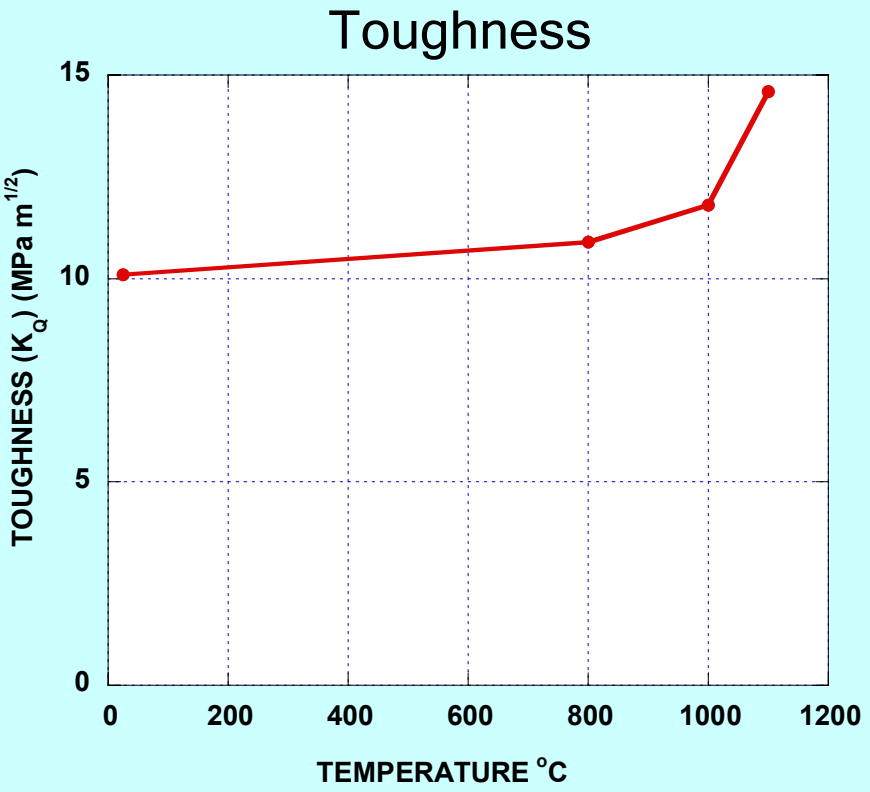
RT



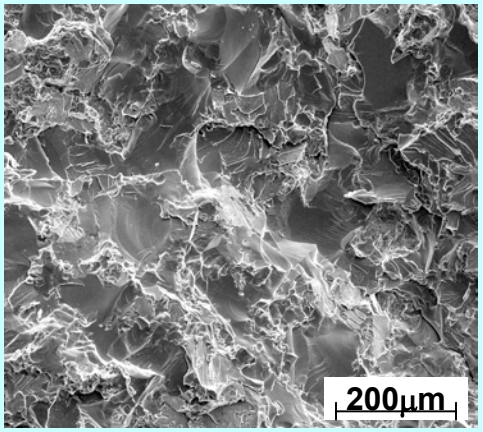
1400°C

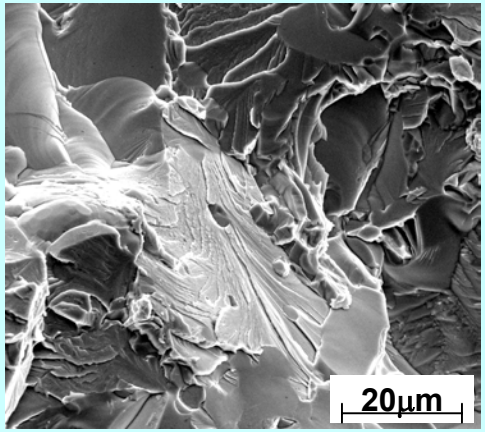
STRENGTH AND TOUGHNESS FOR Nb / Nb SILICIDE



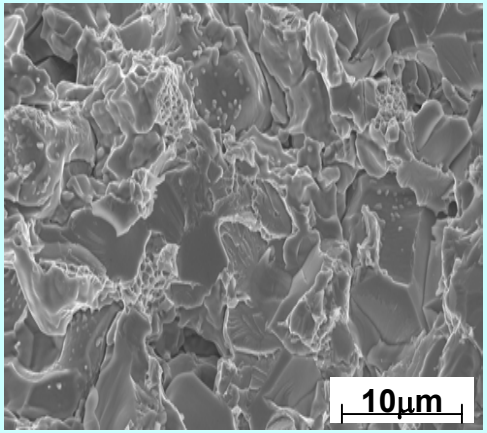


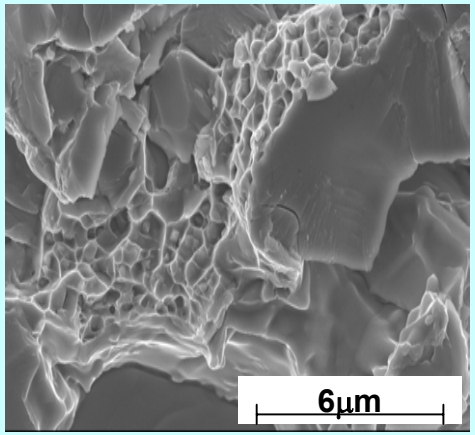
FRACTURE MODES: Nb/Nb Silicides





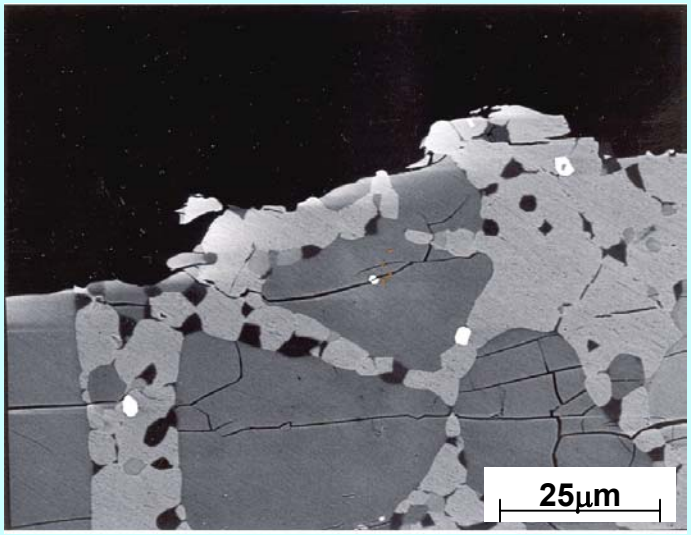
Room Temperature

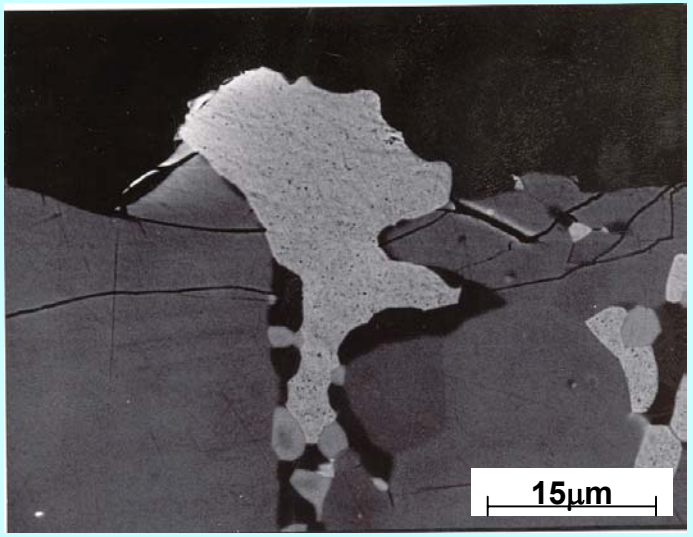


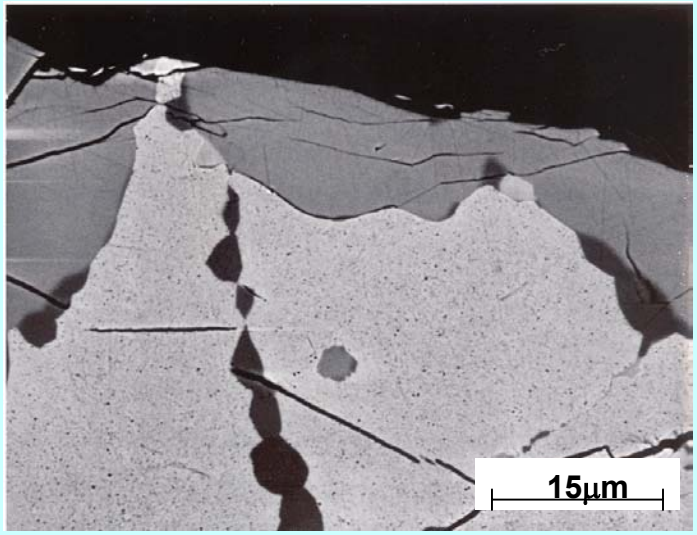


1100°C

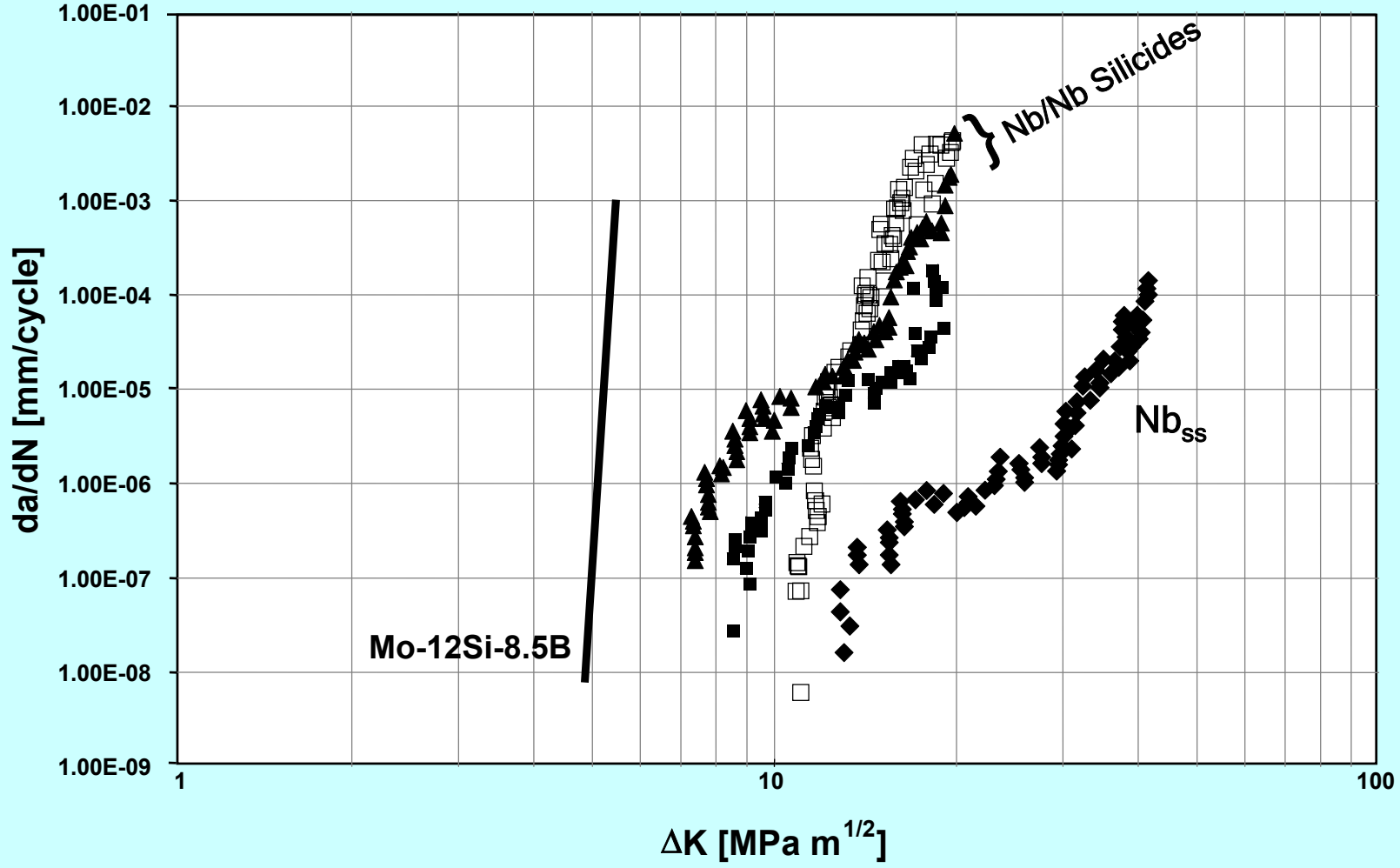
LOW TEMPERATURE DAMAGE MECHANISMS: Nb/Nb Silicides





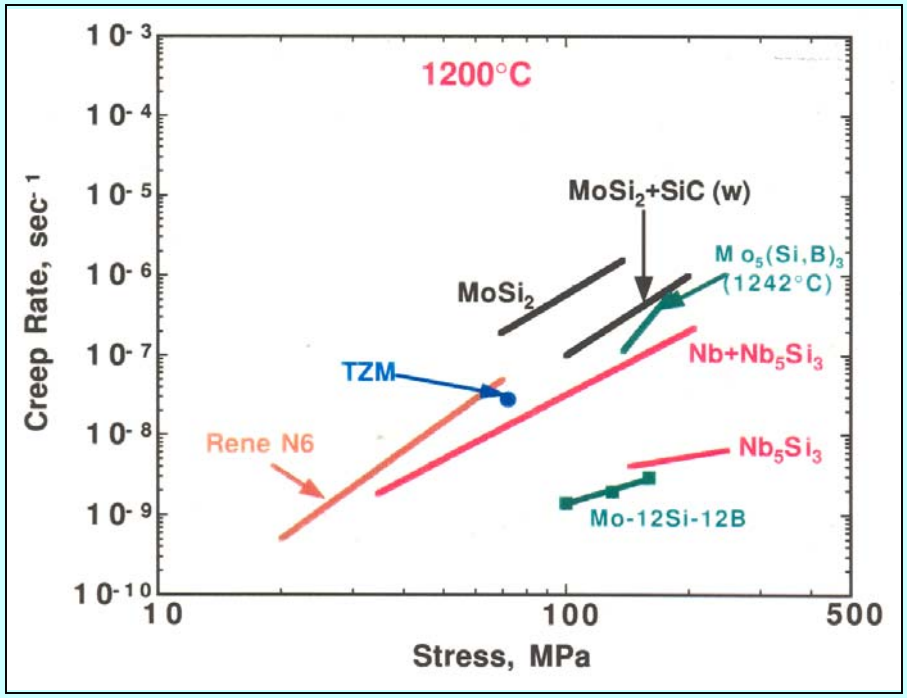


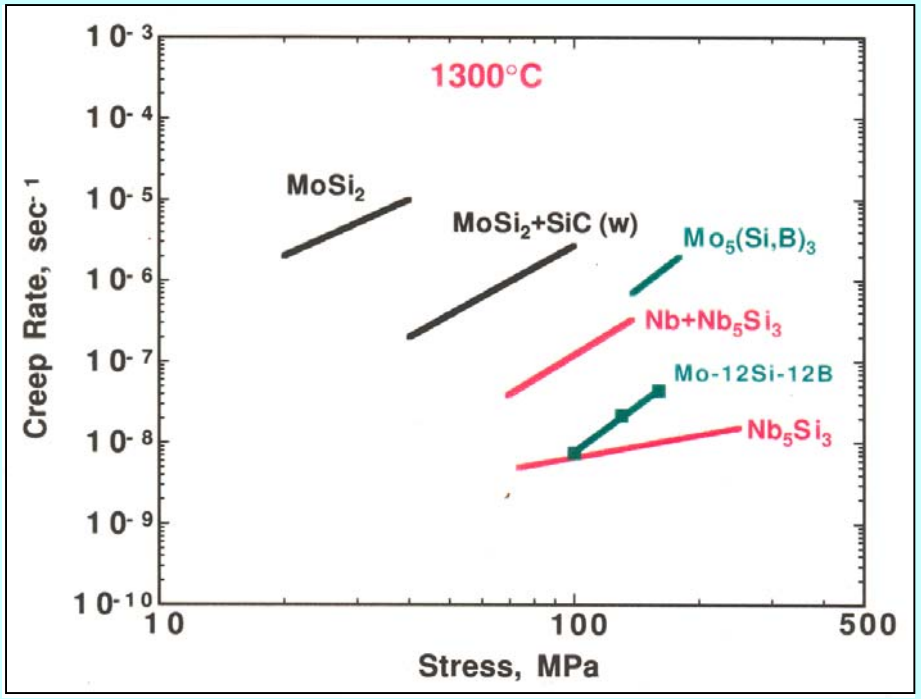
FATIGUE CRACK GROWTH: Nb and Mo Refractory Metal / Silicides



Choe et al: Mo-Si-B & Lewandowski: Nb/Nb Silicides

CREEP BEHAVIOR OF Mo- AND Nb-BASED ALLOYS





SUMMARY / CONCLUSION

- Both Systems Show Promising Microstructural Stability and Reasonable Mechanical Properties i.e., Strength, Creep Resistance and Toughness.
- Both Systems are Brittle at Low Temperatures. Mo-System Exhibits Poor Fatigue and Impact Resistance. Novel Design Methods will be Needed for these Brittle/Ductile Systems
- Oxidation Resistance: Mo System Adequate from 900-1350°C. Nb-System, Limited Protection (~100 h) up to 1200°C. Both Systems will Require Coating.
- Processing and Scale-up are Major Issues for Applications.
- Comprehensive Composition / Processing / Microstructure / Property Data Still Lacking.